

International Atomic Energy Agency (IAEA) Activities on Spent Fuel Management Options

Z. Lovasic, W. Danker
International Atomic Energy Agency (IAEA)
Wagramer Strasse 5, P.O. Box 100, A-1400 Vienna
Austria

ABSTRACT

Many countries have in the past several decades opted for storage of spent fuel for undefined periods of time. They have adopted the “wait and see” strategy for spent fuel management. A relatively small number of countries have adopted reprocessing and use of MOX fuel as part of their strategy in spent fuel management. From the 10, 000 tonnes of heavy metal that is removed annually from nuclear reactors throughout the world, only approximately 30 % is currently being reprocessed. Continuous re-evaluation of world energy resources, announcement of the Global Nuclear Energy Partnership (GNEP) and the Russian initiative to form international nuclear centers, including reprocessing, are changing the stage for future development of nuclear energy. World energy demand is expected to more than double by 2050, and expansion of nuclear energy is a key to meeting this demand while reducing pollution and greenhouse gases.

Since its foundation, the International Atomic Energy Agency (IAEA) has served as an interface between countries in exchanging information on the peaceful development of nuclear energy and at the same time guarding against proliferation of materials that could be used for nuclear weapons. The IAEA's Department of Nuclear Energy has been generating technical documents, holding meetings and conferences, and supporting technical cooperation projects to facilitate this exchange of information. This paper focuses on the current status of IAEA activities in the field of spent fuel management being carried out by the Division of Nuclear Fuel Cycle and Waste Technology. Information on those activities could be found on the web site link www.iaea.org/OurWork/ST/NE/NEFW/nfcms. To date, the IAEA has given priority in its spent fuel management activities to supporting Member States in their efforts to deal with growing accumulations of spent power reactor fuel. There is technical consensus that the present technologies for spent fuel storage, wet and dry, provide adequate protection to people and environment. As storage durations grow, the IAEA has expanded its work related to the implications of extended storage periods. Operation and maintenance of containers for storage and transport have also been investigated related to long term storage periods. In addition, as international interest in reprocessing of spent fuel increases, the IAEA continues to serve as a crossroads for sharing the latest developments in spent fuel treatment options.

A Coordinated Research Project is currently addressing spent fuel performance assessment and research to evaluate long term effects of storage on spent fuel. The effect of increased burnup and mixed oxide fuels on spent fuel management is also the focus of interest as it follows the trend in optimizing the use of nuclear fuel. Implications of damaged fuel on storage and transport as well as burnup credit in spent fuel applications are areas that the IAEA is also investigating. Since spent fuel management considerations require social stability and institutional control, those aspects are taken into account in most IAEA activities. Data requirements and records

management as storage durations extend were also investigated as well as the potential for regional spent fuel storage facilities. Spent fuel management activities continue to be coordinated with others in the IAEA to ensure compliance and consistency with efforts in the Department of Safety and Security and the Department of Safeguards, as well as with activities related to geologic disposal. Either disposal of radioactive waste or spent fuel will be an ultimate consideration in all spent fuel management options. Updated information on spent fuel treatment options that include fuel reprocessing as well as transmutation of minor actinides are investigated to optimize the use of nuclear fuel and minimize impact on environment. Tools for spent fuel management economics are also investigated to facilitate assessment of industrial applicability for these options. Most IAEA spent fuel management activities will ultimately be reported in one of the IAEA technical publications (available at <http://www.iaea.org/Publications/index.html>).

In addition, to the above activities, the Nuclear Fuel Cycle and Materials Section maintain a database and information system as a resource to Member States. During their annual reviews of IAEA spent fuel management activities, Member States have confirmed that the Nuclear Fuel Cycle and Waste Technology Division will continue to have a role in rendering an impact on the sustainability of long term spent fuel management options.

INTRODUCTION

Management of spent fuel arising from nuclear power production has long been considered an important issue due to the political, economic, and societal implications associated with it. In view of the large amount of spent fuel being progressively added to the cumulative inventory in the world, the significance of spent fuel management will continue to grow in the future.

Whereas the nuclear industry continues to successfully manage spent fuel arising from nuclear power production, a variety of associated issues have been raised as countries evaluate and choose policy options for spent fuel management. It is crucial to resolve or mitigate those issues in order to enhance acceptance of the anticipated role of nuclear energy in future sustainable development.

The recent trend toward renewal of interest in nuclear power as a current and future energy option calls for development of innovative nuclear systems in search of technical breakthroughs for sustainable development. Several national and international initiatives have been launched for spent fuel treatment methods with a long term vision for technical innovation in spent fuel management.

As the global energy scene appears to be changing in favor to nuclear energy, there are several initiatives intended to ensure access to nuclear fuel to all Member States without the need to develop fuel processing and reprocessing technologies. The Global Nuclear Energy Partnership (GNEP) and the Russian initiative to form international nuclear centers, including reprocessing, are two such initiatives changing the stage for future development of nuclear energy. World energy demand is expected to more than double by 2050, and expansion of nuclear energy is a key to meeting this demand while reducing pollution and greenhouse gases.

Another recent initiative launched by the IAEA with implications for spent fuel management is the Multinational Approach (MNA) to nuclear fuel cycles. In 2005, the IAEA published an International Expert Group report on Multilateral Approaches to the Nuclear Fuel Cycle. This

report serves as a key resource in the ongoing formulation of initiatives intended to provide assurances of fuel supply and assurances of proliferation resistance [1].

Global statistics in spent fuel management

Currently about 10,500 tHM spent fuel are unloaded every year from nuclear power reactors worldwide. This is the most important continuous growing source of civil radioactive materials generated, and thus need to be managed appropriately. Also, this annual discharge amount is estimated to increase to some 11,500 t HM by 2010. The total amount of spent fuel cumulatively generated worldwide by the beginning of 2004 was close to 268,000 t HM of which 90,000 tHM has been reprocessed. The world commercial reprocessing capacity is around 5000 tonnes per year. Projections indicate that the cumulative amount generated by the year 2010 may be close to 340,000 t HM with a corresponding increase in reprocessed fuel. By the year 2020, the time when most of the presently operated nuclear power reactors will approach the end of their licensed operation life time, the total quantity of spent fuel generated will be approximately 445,000 t HM [2].

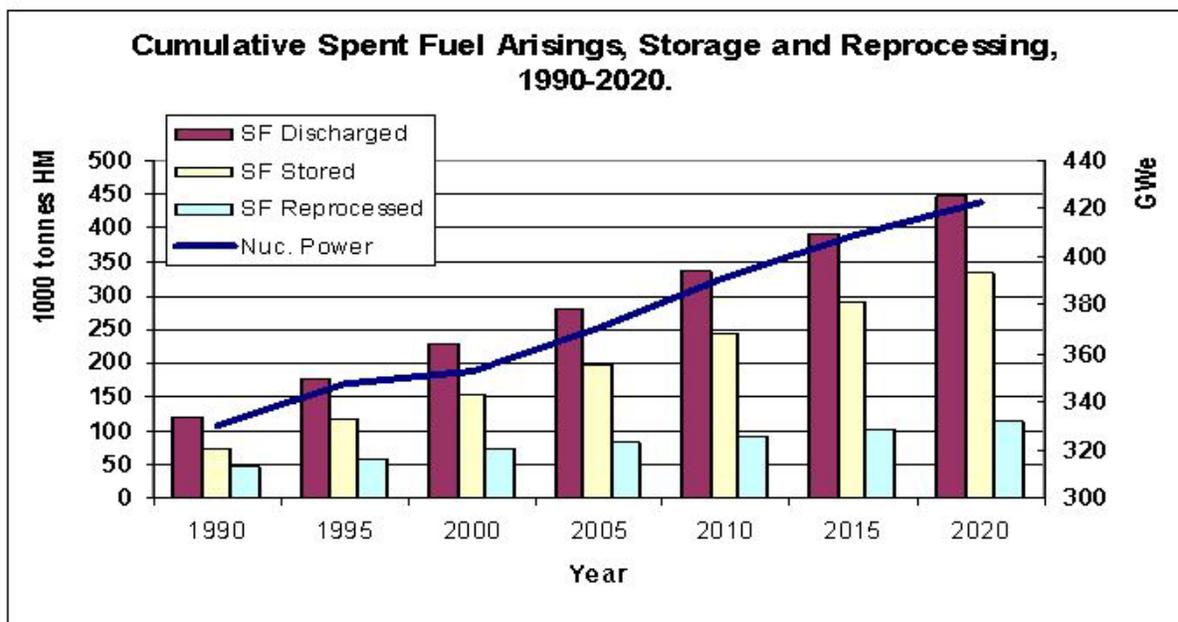


Figure 1. Trends in spent fuel management

SPENT FUEL MANAGEMENT STRATEGIES

Spent fuel contains significant amounts of fissile materials that can be recycled into new nuclear fuel by reprocessing and refabrication into new fuel assemblies. This so-called closed fuel cycle is believed to be a source of abundant energy supply to ease problems with fossil fuel reserves. As noted in the statistics above, only 30 % of spent fuel generated world wide has been reprocessed. Anticipating subsequent reprocessing of spent fuel, only relatively small capacities for temporary spent fuel storage had been built in the past. The block diagram in Figure 2 shows

current perspectives on spent nuclear fuel as being waste or assets. These are major political and economic factors for Member States to consider in developing their spent fuel management strategy. Many of the Member States have adopted one of two approaches for the rest of the spent fuel. In countries opting for the “direct disposal” approach, the fuel will be stored until a final geological repository will be available. Other countries have adopted a “wait and see” approach, pending further developments including the possibility of economic breakthroughs in spent fuel management.

These changes in spent fuel management strategies led to a shortage of storage capacities in most Member States with nuclear power plants. Therefore, most of the spent fuel storage pools have been re-racked, and re-licensed to accommodate larger amounts of spent fuel for longer periods of time than originally planned. If possible, the storage capacity was extended to lifetime operation of the power reactor. In recent years, fuel management strategies led to increases in the initial enrichment and consequently the fuel burnup in order to reduce the amount of spent fuel. These strategies result in longer cooling times prior to further treatment either by reprocessing or conditioning for direct disposal. Newer spent fuel storage pools are in most cases large enough to accommodate all of the spent fuel accumulated during the lifetime of the reactor. In cases where such methods were not possible, additional storage capacities had to be provided by Away from Reactor (AFR) type storage facilities. Many Member States have already built such storage facilities.

The options selected by each country for interim storage of spent fuel are driven by a variety of factors including economics and safety. For AFR storage, there has been a growing preference for modular dry storage options which have become mature and competitive in the current market.

Technology continues to evolve, however, to comply with emerging requirements from recent trends toward higher burnup and MOX fuel as well as toward longer storage durations. For long term storage, maintaining spent fuel integrity to ensure eventual retrievability (and address confinement and criticality considerations), together with retention of relevant records, are key objectives.

The diagram in Figure 3 shows the sequence of the main spent fuel treatment options and their interfaces. It is obvious from their interfaces that spent fuel storage and disposal either of spent fuel or radioactive waste from reprocessing are essential phases of any strategy.

IAEA ACTIVITIES IN SPENT FUEL MANAGEMENT

The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management and the IAEA Safety Standards provides a framework for the international safety regime for spent fuel management. The transport of radioactive material, including spent fuel, provides a well established example of this international safety regime through nearly universal application of the IAEA Transport Regulations.

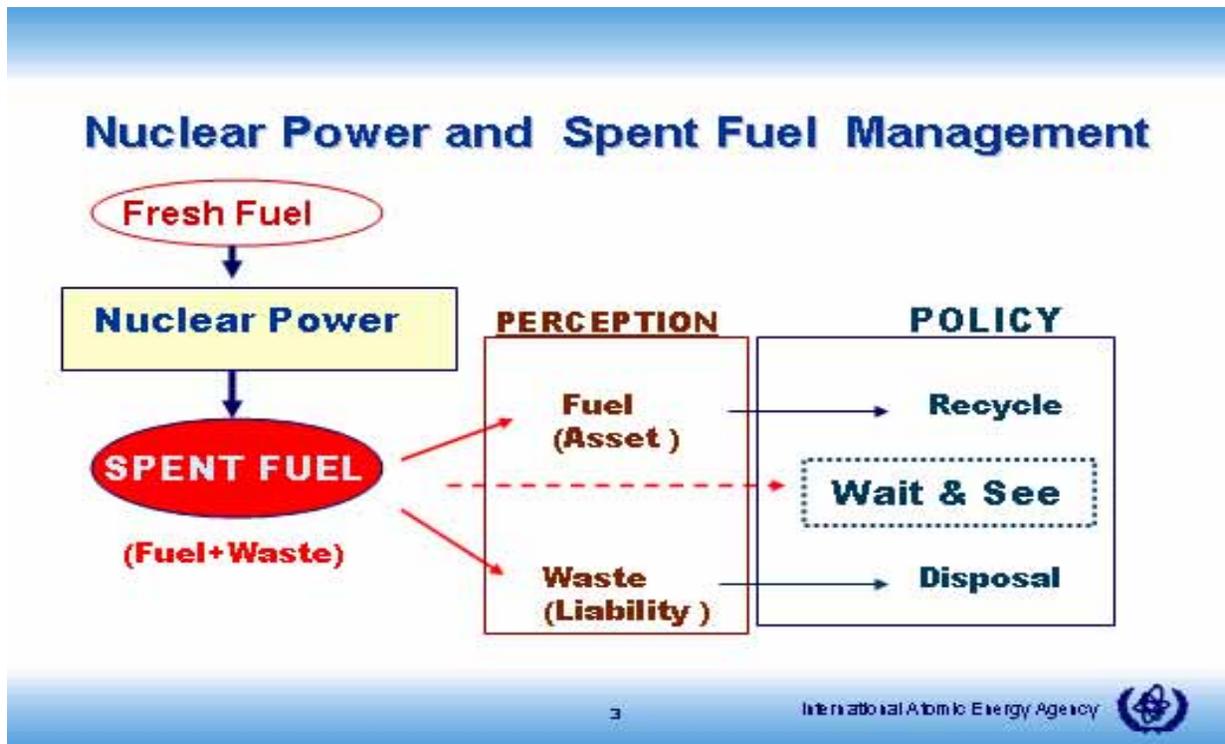


Figure 2. Spent fuel perspectives

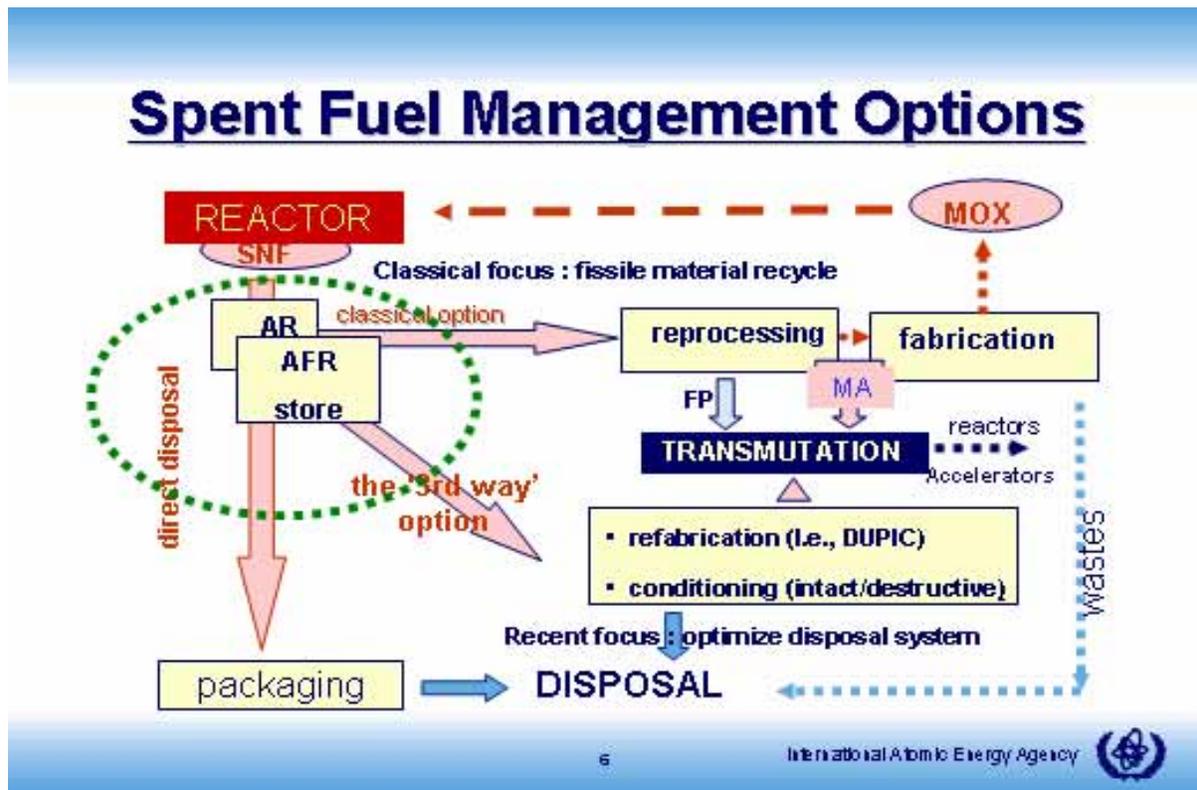


Figure 3. Spent fuel management options

In response to the needs of Member States, the IAEA continues to give a high priority to safe and effective implementation of spent fuel management. As an example of continuing efforts, the International Conference on Management of Spent Fuel from Nuclear Power Reactors held in June 2006 provided a major forum (150 participants from 36 countries and 4 international organizations) for information exchange on this important subject. Another example is the technical meeting on burnup credit applications organized by the IAEA in London and attended by 60 participants from 18 countries. Further information regarding Agency activities in the area of spent fuel management can be accessed at:

http://www.iaea.org/worldatom/Programmes/Nuclear_Energy/NEFW/nfcms_b3.html].

These activities include plans to produce technical documents as resources for Member States on the following topics: spent fuel performance and research, burnup credit applications, cask maintenance, container loading optimization, long term storage data needs including records maintenance, economics, spent fuel treatment, and influence of fuel design on spent fuel storage.

Member States typically help plan IAEA programmatic activities through the Technical Working Group on Nuclear Fuel Cycle and Spent Fuel Management (TWGNFCO) which meets periodically.

TWGNFCO participants at the 2006 meeting confirmed the following activities in spent fuel management for 2008-9 (in addition to ongoing continuing activities such as technical cooperation with other organizations):

- Technical document on Spent Fuel Performance Assessment and Research (SPAR-II);
- Technical document on burnup credit applications;
- Proceedings of international conference on management of power reactor spent fuel;
- Technical document on implications of damaged spent fuel for storage and transport;
- Technical document on storage facility operations and lessons learned;
- Technical document on systems integration considerations in spent fuel management;
- Technical document on the influence of fuel design for high burnup and MOX fuel and advanced reactor operations on spent fuel storage;
- Technical document on spent fuel treatment options and applications;
- Technical document on methodologies and tools for spent fuel management economics;
- Technical document on the technical and institutional aspects of regional spent fuel storage facilities.

The following paragraphs describe a few of the latest activities related to spent fuel management that are intended to result in published reports/documents.

Spent Fuel Data Collection and Records Management

One of the vital issues for long-term management of spent fuel is the retention of appropriate information which must accompany the spent fuel itself for the time span required down to its endpoint. Due to safety, safeguards and security implications, as well as for operational needs, the significance of spent fuel data management will persist as long as the spent fuel has to be

managed for its lifetime. Data collection and maintenance for spent fuel are required from the earliest phase of any project for spent fuel management. From a practical point of view, however, it is a challenge to define which data must be retained, for how long it must be kept and by what methods.

Spent nuclear fuels contain some nuclides of special importance in data management. While the fissile content is the key interest for recovery by reprocessing, the minor actinides are of principal concern in the case of spent fuel disposal because of their long half-life and radio-toxicity. The recent concept of total cycle management in repository performance requires accounting of all the nuclides data, while data on the spent fuel content is required for such a case as direct reuse of spent fuel by re-fabrication without separating particular radio-nuclides. It is quite obvious that adequate data must be available when necessary, in order to make an informed decision either for technical or administrative issues.

In the area of radioactive waste management, several Technical Documents (TECDOCs) have been issued by the IAEA on related subjects, i.e.:

- IAEA-TECDOC-1097 “Maintenance of records for radioactive waste disposal” (1999).
- IAEA-TECDOC-1222 “Waste inventory record keeping systems (WIRKS) for the management and disposal of radioactive waste” (2001).
- IAEA-TECDOC-1398, “Records for radioactive waste management up to repository closure: managing the Primary Level Information (PLI) set (2004).

Whereas some of the information provided by these publications is applicable to nuclear fuel management, there are technical particularities pertaining to spent fuel management that still have to be addressed. This TECDOC is intended to provide additional information, by reviewing issues and identifying relevant data required for spent fuel management.

Coordinated Research Program on Spent Fuel Performance Assessment and Research (SPAR II)

As spent fuel storage is an essential phase in any spent fuel management option, and long term storage (for 50 years and possibly more) is likely in particular for some countries that have adopted the “wait and see” approach, maintenance of spent fuel integrity during storage is an important issue. Therefore, the Agency has coordinated investigations of spent fuel behavior in storage for over twenty years. Coordinated research to date has indicated positive experiences with wet and dry storage of spent fuel [3]. Nevertheless, prospects of long term storage have raised the need for continuous investigation of long term effects and potential deterioration mechanisms on spent fuel.

Presently, spent fuel is mostly stored wet in at reactor (AR) or away from reactor (AFR) storage facilities. The use of wet vs. dry storage in AFR varies per regions as shown in Figure 4.

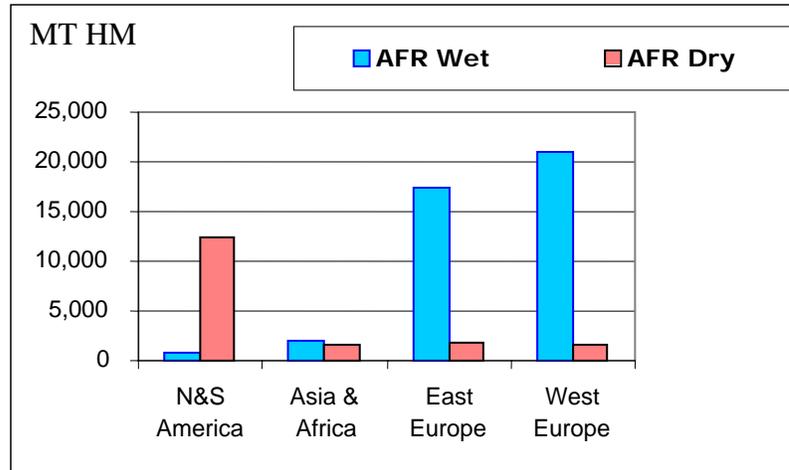


Figure 4: Wet vs. dry storage in AFR per world regions

Because many AR pools are approaching their full capacity, even after extensive reracking, storage of spent fuel under dry and inert atmosphere is increasingly being used.

The situation is further complicated with the today's tendency to use higher enrichment, higher burnup and mixed-oxide fuels to optimize the use of nuclear fuel. Given the higher decay heat levels from these fuels, prolonged wet storage will remain preferred approach for interim storage during the first decade after discharge.

Operation and Maintenance of Spent fuel Storage Casks/Containers

While casks have been an essential part of the nuclear industry's transportation of radioactive materials for decades, that role has significantly expanded in recent years, particularly with respect to the dry storage of spent fuel for plant sites around the world. While the majority of the world's spent fuel is still kept in the classic water pool, trends show that most new storage systems are built to take advantage of the practical passive and modular features of casks and containers as an effective option for short- and long- term storage of spent fuel. Spent nuclear fuel has been stored safely in pools or dry systems for decades in over 30 countries. This international storage tradition has resulted in a vast technical record, as well as an appropriate understanding of the operational practices, that are beneficial for spent fuel storage. In addition to the historic study of spent fuel transportation, industrial experience has also been accumulating in the use of casks and containers for storage, both with dedicated or dual-purposes, in an increasing number of Member States. Valuable knowledge in cask operation and maintenance is also available from spent fuel storage sites around the world, combined with relevant regulatory experience.

In view of the expanding need for casks in a growing number of Member States, for both transporting and storing spent fuel, a combined knowledge of the technical commonalities found in both transportation casks and spent fuel storage containers can provide for improved planning and implementation in future cask use projects. It may also help build public confidence, which has become a crucial issue to nuclear projects.

There are several international resources providing technical information on transportation and storage casks, as represented by PATRAM (International Symposium on the Packaging and Transport of Radioactive Materials) and a few meetings organized by IAEA. However, given their increasing application, there was a need to provide a review of experiences on operation and maintenance of transport and storage casks/ containers. The only IAEA publication related to this topic was a document focused on the decontamination of transportation casks [4].

Some important measures have developed for the contamination-free operation of casks in the past several years in Europe, thus enriching the knowledge base for cask operation and maintenance for spent fuel storage, as well. This TECDOC is intended to provide comprehensive guidance on the major issues to be considered for cask operation and maintenance associated with spent fuel storage from knowledge gathered from industrial practices and research results associated with the use of cask and containers for spent fuel transportation and storage.

Selection of Away from Reactor Facilities for Spent Fuel storage

This document aims to provide guidance and information on the approaches and criteria that would have to be considered for the selection of Away-From-Reactor (AFR) spent fuel storage facilities, needs for which have been growing in an increasing number of Member States producing nuclear power. The AFR facilities can be defined as a storage system functionally independent of the reactor operation providing the role of interim storage until a further destination (such as final disposal) becomes available. Initially developed to provide additional storage space for spent fuel, some AFR storage options are now providing additional spaces for extended storage of spent fuel with a prospect for long-term storage, which is becoming a progressive reality in an increasing number of Member States. Continuing debate on issues associated with the endpoints for spent fuel management and consequent delays in the implementation of final steps, such as ultimate disposal, will extend this trend.

The importance of AFR facilities for interim storage of spent fuel has been recognized for several decades and addressed in various IAEA publications in the area of spent fuel management. The Guidebook on Spent Fuel Storage (TRS-240 published in 1984 and revised in 1991) discusses factors to be considered in the evaluation of spent fuel storage options. A Technical Committee Meeting (TCM) on Selection of Dry Spent Fuel Storage Technologies held in Tokyo in 1995 also deliberated on this issue. However there has not been any stand-alone document focusing on the topic of selection of AFR storage facilities.

The selection of AFR storage facilities is in fact a critical step for the successful implementation of spent fuel management programs, due to the long operational periods required of storage and significant fuel handling involved with the additional implication of subsequent penalties in reversing decisions or changing the option mid-stream especially after the construction of the facility. In such a context, the long-term issues involved in spent fuel storage, including long-term caretaking/refurbishment of facilities or transition from one option to another in consideration to evolution of technology, changes in long-term policies, market-based influences, as well as changes in regulatory criteria, deserve careful consideration.

Whereas it can be said that competitive services for AFR storage are currently available from the market, it is often not evident how to choose the best option or technologies for a storage in need because of the complex issues involved in the decision, including a range of future uncertainties. Furthermore, issues in selecting an AFR storage facility can shift from time to time as spent fuel

management policies, strategies and technologies advance. They can differ from one country to another due to considerations particular to those countries, as well as some common issues such as the trend toward privatization of former public enterprises in this sector. They have entailed, together with the issue of public involvement, some profound impacts on the nuclear industry in general and spent fuel management in particular. This TECDOC attempts to provide guidance in the approach to select AFR facilities for spent fuel storage.

Spent Fuel Treatment Options

The management of spent fuel arising from nuclear power production is a crucial issue for the sustainable development of nuclear energy. While reprocessing of spent fuel was historically the favored strategy for the back end fuel cycle, in the past few decades some countries have turned to other options. Specifically some countries have adopted a direct disposal or a 'wait and see' strategy, partly in response to concerns such as nuclear weapons proliferation, public acceptance and economics.

The IAEA has issued several publications [5, 6, 7 and 8] in the past that provide technical information on the global status and trends in spent fuel reprocessing and associated topics, and one purpose of this present publication is to provide an update of this information.

Influence of High Burnup Fuel and MOX Fuel on Spent Fuel Management

There is a continuing trend towards achieving higher burnup for UOX and MOX fuels and increasing use of MOX fuel in the nuclear power industry with relevant implications which will have to be addressed in the spent fuel management, including, among others, storage, transportation, reprocessing, disposal and other potential options to be introduced in the back-end of the nuclear fuel cycle in the future.

Burnup extension is being increasingly viewed not only in terms of fuel utilization but also in terms of the overall waste management strategy. The issues associated with spent fuel management arising from high burnup UOX and MOX fuel use had been reviewed earlier in the framework of International Working Group on Water Reactor Fuel Performance and Technology (IWG-FPT) in the IAEA. A series of technical committee meetings (TCMs) and symposiums on the subject were held in the past, resulting in the publication of reports [9, 10] both of which provided a summary of issues associated with high burnup fuel (and MOX fuel use) in the fuel cycles. A decade later, another report [11], provided an updated overview of the worldwide state of MOX fuel development and use, based on the information collected from Symposium on MOX Fuel Cycle Technologies for Medium and Long Term Deployment which was held in 1999 in Vienna International Centre.

This project is an extension of those past activities of the IAEA to look at the impacts of increase in burnup and MOX fuel use on the spent fuel management with the goal to produce an updated Technical Document (TECDOC). The topical arrangement of this TECDOC will be based on the old TECDOC-699 with a magnified look at the impact of burnup extension and the expanding use of MOX fuel in response to the increasing need for Member States for information on the evolution of technical requirements associated with spent fuel management.

FUTURE DIRECTIONS

The work carried out within the IAEA so far and frequent requests from Member States have pointed to a need for a reliable cumulative data on stored spent fuel updated yearly. The endeavor will continue in gathering reliable data on yearly generation of spent fuel, quantities that are stored and quantities that are reprocessed. The planned activities that were discussed above and confirmed by Member States through the Technical Working Group on Nuclear Fuel Cycle and Spent Fuel Management (TWGNFCO) will be pursued. The current focus continues to be on studying spent fuel performance during wet and dry storage, influence of high burnup and MOX on spent fuel management, handling damaged fuel, burnup credit applications, spent fuel management economics and optimization of spent fuel storage strategies (i.e. centralized storage facilities).

Reprocessing and advanced reactor operations and fuel cycles will be investigated more as an endeavor to make nuclear power a more sustainable source of energy and to minimize the environmental burden for disposal. Processes that are shown to be more proliferation resistant will be favored vs. classical processes with separation of Plutonium. Partitioning and transmutation of minor actinides are intended to minimize burden of long lived radioisotopes for waste disposal and will continue to be investigated. These development activities, although not directly topics of the Agency's spent fuel management unit, will be setting the stage for priorities in future activities related to spent fuel management.

REFERENCES

1. Multilateral Approaches to the Nuclear Fuel Cycle: Expert Group Report submitted to the Director General of the International Atomic energy Agency, INFFCIRC/640, International Atomic Energy Agency (2005).
2. Nuclear Fuel Cycle and Materials Section Brochure, IAEA International Atomic Energy Agency (2006).
3. Spent Fuel Performance Assessment and Research, IAEA TECDOC-343, International Atomic Energy Agency (2003).
4. Spent Fuel Storage and Transport Cask Decontamination and Modification, IAEA TECDOC-1081, International Atomic Energy Agency (1999).
5. Reprocessing of Highly Irradiated fuel, IAEA-115, International Atomic Energy Agency (1970).
6. Treatment of Irradiated LWR Fuel, IAEA-TECDOC-333, International Atomic Energy Agency (1985).
7. Status and Trends in Spent Fuel Reprocessing, IAEA-TECDOC1103, International Atomic Energy Agency (1999).
8. Status and Trends in Spent Fuel Reprocessing, IAEA-TECDOC-1467, International Atomic Energy Agency (2005).

9. Water Reactor Fuel Extended Burnup Study, IAEA Technical Report Series (TRS) No.343, International Atomic Energy Agency (1992).
10. Impact of Extended Burnup on the Nuclear Fuel Cycle, IAEA TECDOC-699, International Atomic Energy Agency (1993).
11. Status and Advances in MOX Fuel Technology, TRS No.415, International Atomic Energy Agency (2003).